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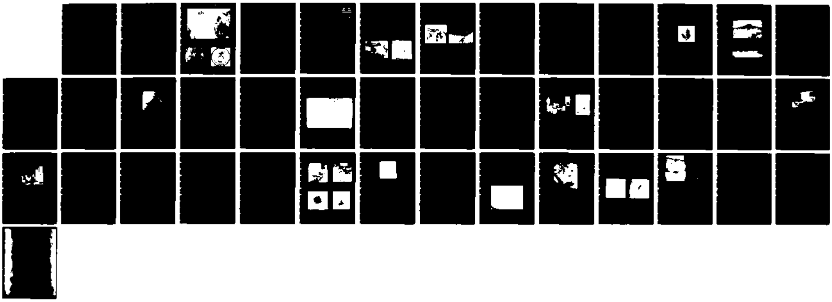

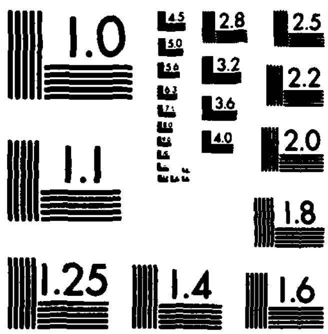
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DEFENSE MAPPING AGENCY:
THE DIGITAL REVOLUTION

DEFENSE MAPPING AGENCY
FOR THE GOOD OF THE COUNTRY
UNITED STATES OF AMERICA

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COVER FIGURES

Top: Analyst Viewing Sensor Image Simulator Softcopy Display of Surface Feature Data over Huntsville, Alabama.

Bottom Left: Softcopy Intensity-Hue-Saturation Transformation Display of Shaded Relief and Surface Feature Data over Seattle, Tacoma, and Mt. Rainier

Bottom Right: Seal of the Defense Mapping Agency.

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DEFENSE MAPPING AGENCY: THE DIGITAL REVOLUTION

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INTRODUCTION

The Defense Mapping Agency (DMA) is undergoing a revolutionary change in its method of operations. During the 1970's, the requirement for mapping, charting, and geodetic (MC&G) products changed swiftly from an emphasis on analog to digital products. These digital products are utilized by U.S. Department of Defense computer based planning, training, and weapons systems. In order to meet the increasing demand for these products, DMA has moved into an interactive computer production environment with a full scale developmental program to place DMA into a nearly all digital production environment in the 1990's. This paper presents the current state-of-the-art production environment within DMA, and describes the challenges to be met during the digital revolution.

OVERVIEW

DMA was officially established in 1972 as a separate defense agency, reporting to the Secretary of Defense through the Joint Chiefs of Staff. As it developed, DMA absorbed about 80 percent of the Mapping, Charting, and Geodesy (MC&G) capabilities of the various

services, which had involved nearly 12,000 individuals and budgets totalling some $200 million. Along with the reorganization of those early years, which was directed towards eliminating duplication of effort and insuring the best use of facilities, came the decision to increase responsiveness to the new, electronic technology which was to revolutionize the MC&G profession.

At about the same time, military photogrammetrists, working with aerial photographs, harnessed emerging technology to develop the first generation of digital topographical data, using stereo photography to calculate terrain factors so contour lines showing the earth's elevations could be generated more rapidly and economically.

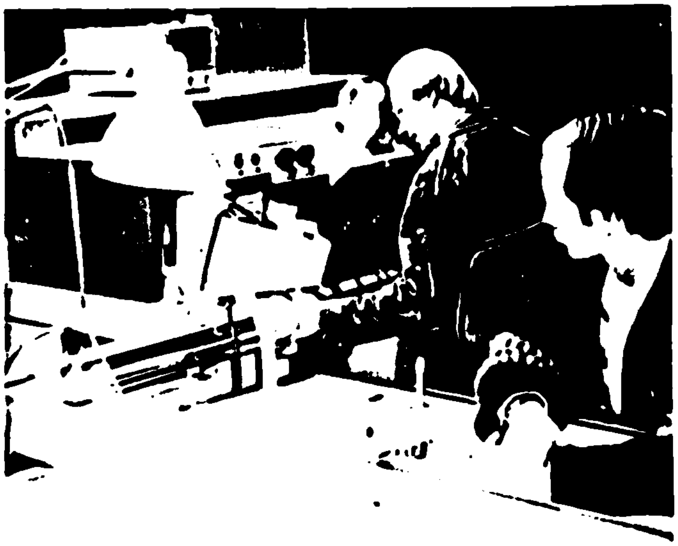

FIGURE 1. Analytical Stereoplotter for Digital Terrain Data Production Based on Stereo-profiling Techniques

FIGURE 2. Mt. Rainier, Mt. St. Helens, and Mt. Adams: Digitally Generated Contours from Digital Terrain Elevation Data.

This was the beginning of a highly sophisticated process for the collection of terrain elevation data. Originally intended to speed production of traditional paper maps, this digital data suddenly became the key to such modern weapons systems as the cruise missile, which carries its own computer (figure 4).

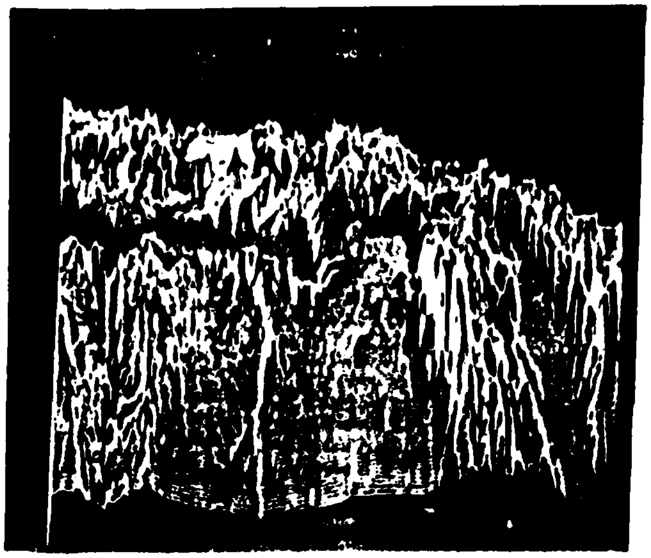

FIGURE 3. Digital Terrain Elevation Data Profile Display

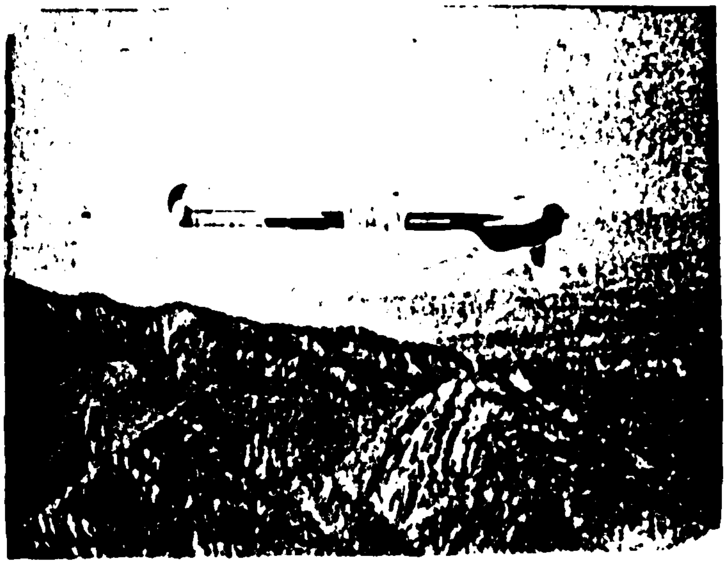

FIGURE 4. Cruise Missile: Guidance System Utilizes DMA Digital Terrain Data

DMA became actively involved in developing three basic types of digital data for the Cruise Missile. The first two of these, Digital Terrain Elevation Data and Vertical Obstruction Data, are being used for missile penetration planning. The third type,

Terrain Contour Matching Data, is more detailed and used for real-time missile guidance of the flight.

The continuing expansion of the country's strategic arsenal and increased force readiness required DMA to expand its capabilities to meet growing requirements for weapons systems support. DMA's role in research and development was expanded, and significant advances kept the agency at the forefront of some of the most radical changes in application of state-of-the-art technology in digital data processing, photogrammetry, cartography, geodesy, and photography -- perhaps the most radical changes in the history of the profession.

In the mid-1970's, DMA made important advances in the vital field of point positioning -- that is, determining the location and relationships of different points of the Earth's surface. In addition to the Doppler system, by which signals from orbiting satellites are used to locate a precise point on the Earth, a new technique, known as inertial positioning, was developed to determine the positions and elevations of points relative to one another. Mounted in land vehicles or helicopters, a device known as the Inertial Positioning System has been operated by DMA since 1975 and is generating unprecedented relative positioning accuracies -- vital to advanced weapons systems such as the MX missile.

This period also saw a revitalization of DMA's crisis support procedures and establishment of formal crisis response structures within the agency. Rapid response requirements were fulfilled in support of a large number of operations around the world. By the beginning of the 1980s, the DMA had more than 8,500 military and civilian personnel and an annual budget in excess of $350 million.

As the Defense Mapping Agency moved into the 1980s, the transition from conventional to digital mapmaking continued, to the point where more than half of the effort at DMA is now directed towards production of digitized products, as opposed to traditional paper maps and charts. The agency is well into the era where its MC&G products are being used directly by the on-board computers of "smart" weapons. In addition to the Cruise Missile, such systems as the FIREFINDER artillery-locating radar, the PERSHING II terminal guidance radar, and a wide range of mission planning simulators and command control systems all depend upon DMA products as an indispensable part of their functions.

The development, test and evaluation, and operational deployment, of the MX and TRIDENT II systems will require significant geodetic

and geophysical data and products from DMA to meet their respective timetables. To keep ahead of these and other growing requirements, special programs were established to accelerate development of computerized production techniques at DMA, to best utilize vast amounts of data collected by advanced acquisition systems. This capability is essential if DMA is to meet the expanding MC&G requirements of the next decade.

Modern day military aircraft are expensive to operate; its more economical and often more efficient to "fly" these missions under the realistic simulation available today. DMA data is used in simulators for the C-130, B-52, F-111, F-16, A-6E and other aircraft, as well as in the Space Shuttle, to train air crews, avoid wear and tear on equipment and reduce fuel costs -- and save lives. Data used in all these programs, and increasingly in the production of more conventional maps and charts, is constantly being accumulated in the massive DMA Digital Landmass System (DLMS) data base, which contains terrain elevation and feature anslysis data, comprised of worldwide "natural" information (rivers, forests, mountains, etc.) plus "culture" data (manmade bridges, roads, homes, factories, etc.)

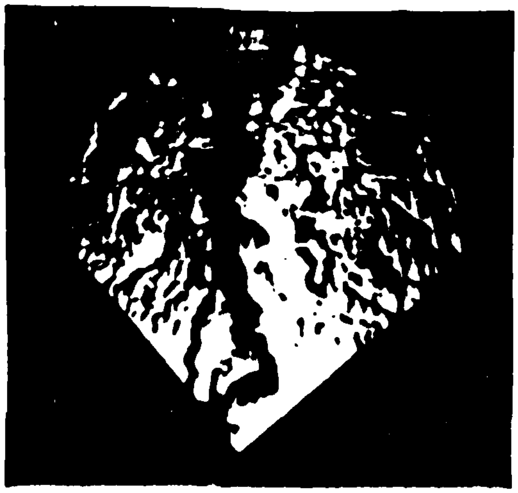

FIGURE 5. Computer Generated Radar Image Using DMA Digital Terrain and Feature Analysis Data Transformed by a Digital Model of Radar Physics and Receiver Electronics.

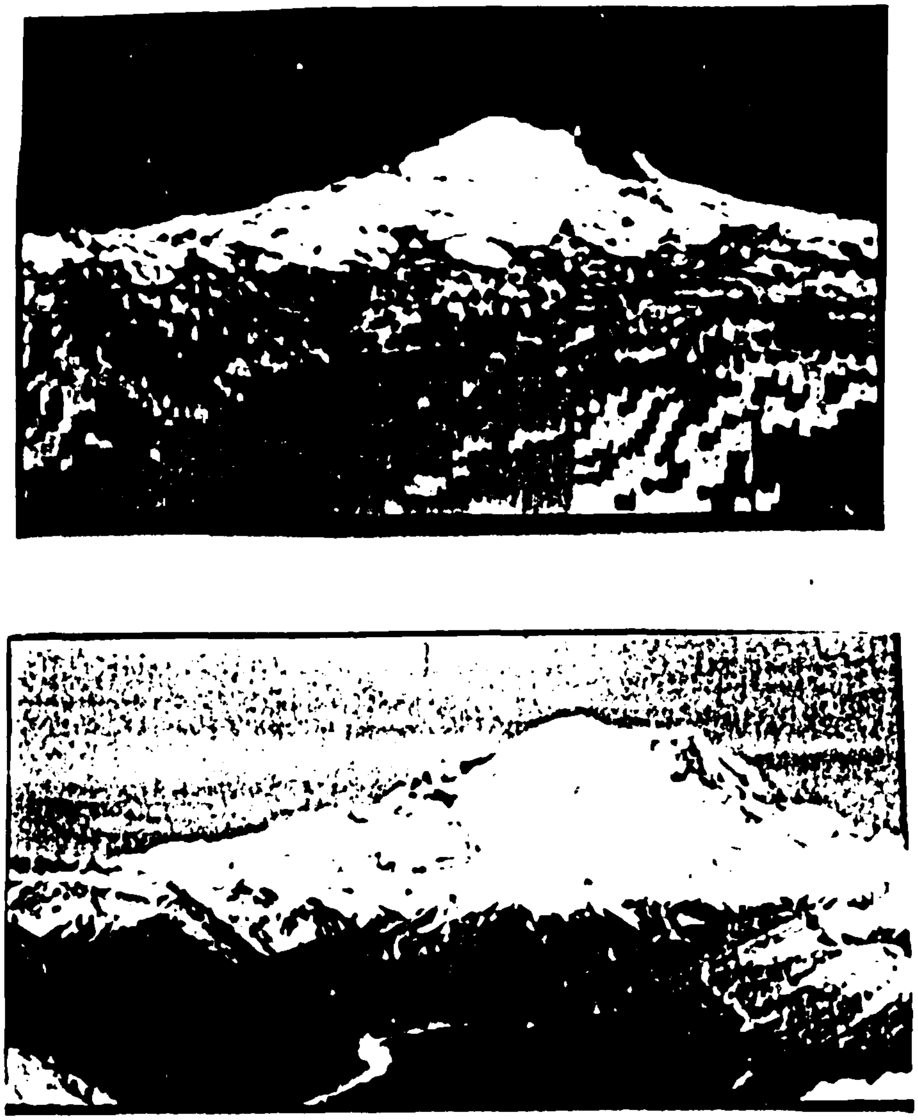

FIGURE 6. Computer Generated Visual Scene of Mt. Rainer (top) Compared with Actual Scene (bottom). Differences in amount of Snow Cover are a Result of Mid-Summer Conditions in the Data and a Spring Photograph.

The increasing availability of communications satellites, the advent of fiber optics and the growing capability of processor-to-processor communications permit the rapid transmission of ever-increasing amounts of data. The challenge here to DMA is to design a system which will permit transmission of its digital data directly to the user. At the same time, the traditional paper maps and charts will be in use by the Armed Forces for many years to come. Increased use of digital production techniques will greatly improve the efficiency and accuracy of more traditional priting processes and, in the future, likely lead to direct input of digital information to paper.

Smaller data bases are being developed as needed to support various military systems and, probably within the next decade, they will be joined to form a unified data base. The dramatic strides made in recent years in harnessing computer technology, for use in both the compilation and cartographic functions of mapmaking, will insure that DMA maintains its capability of producing vast amounts of MC&G data in digital form, readily available for retrieval to support a variety of military needs.

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DATA BASE

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nature of the task, the produ
ranges from 100 to 1000 times
data, depending upon the area.
program covers roughly 24 mill

miles, with estimated data base completion between 1990 and 1995. Level II data is programmed only for small selected areas of interest.

FIGURE 7. Color Coded Digital Terrain Elevation Data over Mt. Rainer, Mt. St. Helens, and Mt. Adams.

The DLMS data bases, critical to the success of aircrew and simulator training, have been shown to be adequate for support of long and medium range radar simulation using Level I Resolution (Figure 5), and for short range radar simulation where Level II data is available. In addition, these data bases have shown some applicability for multi-sensor simulation. As microelectronic technology improves, however, on-board multi-spectral electro-optical navigation sensors continue to acquire and display terrain and cultural information with ever increasing resolution approaching that of the human visual system.

Simulator training is required for aircrews in the use of advanced aircraft sensor displays, including forward looking infrared systems, low light level television, ultra-high resolution, and real-time synthetic aperture radar, as well as an increased demand for visual training (Figure 6) associated with low altitude mission profiles. Technology improvements will also allow greater realism in advanced simulators, and the demonstrated effectiveness of present simulators is driving requirements for simulators to support the new generation of navigation sensors. In addition, the development of various types of weapon system guidance correlators are demanding new support data. Correlation may be made against pre-stored computer generated reference scenes for optical, infrared, microwave, conventional and synthetic aperture radar, and ultra-violet electro-optical sensors.

A crucial component in support of these new navigation and guidance systems is the ability to provide adequate digital data bases that describe a variety of global ground truth conditions. Both static and time-varying information such as texture, thermal and near-infrared properties, precise geometric properties, road patterns, population and traffic density patterns, and atmospheric weather data will be required in addition to current DLMS feature descriptors. Along with new types of feature descriptors, increased resolution and level of detail will be required.

Initially, much of the above data will be impossible to collect in some cases and will not be cost effective in others, and will have to be modeled from known data. As automated image analysis and feature extraction techniques become developed using image understanding and artificial intelligence concepts, an increasing amount of these data types will be collected and included in

the cultural data base. As an interim procedure or for data base areas where higher resolution data is required only for increased data content and appearance, and not for reasons of precise ground truth, computer techniques such as texturization and synthetic feature break-up allow for the production of large data base coverage using existing techniques. It is becoming increasingly apparent, however, that precision data bases will be required after 1985 with additional feature descriptors and resolutions on the order of 10 feet. Current production manpower resources limit Level II data to small geographic areas of interest, and entirely prohibit this ultra-high resolution data. Production of large area, high resolution data bases is unattainable without both adequate source data and automated feature extraction techniques.

FIGURE 8. COMPUTER GENERATED SLOPE MAP

This shaded relief map of the Pacific Northwest was computer generated by the Defense Mapping Agency from cartographically derived Digital Terrain Elevation Data. This $4^{o}x6^{o}$ area is comprised of slope information computed from approximately 35 million discrete digital terrain elevation values spaced at 3 arc second intervals and printed in geographic coordinates by a computer photo-write system.

OVERVIEW OF DIGITAL DATA PRODUCTION IMPROVEMENTS

The feature analysis production task is entering a transition stage, advancing from current manual and associated analog, off-line processing to distributed data processing systems. These systems introduce real-time, on-line, remote work station concepts and are based on analytical photogrammetric methods and digital image processing techniques for semi-automated feature extraction, interactive editing, quality control, and sensor simulation.

The first steps to improve and enhance the DFAD production process were the results of initiatives taken in 1975 which identified and ultimately effected the acquisition of the Digital Interactive Multi-Image Analysis System (DIMIAS). This equipment (Figure 4) is used primarily to analyze and extract landscape features from digital imagery in a semi-automated mode. The primary application is for rural or remote areas as opposed to urban areas. The system combines the analysis and digitization operations for landscape features. The requirements for the feature analysis and digitization processes are essentially the same as for manual methods: registration of digital imagery to geodetic control, analysis of imagery, mensuration, definition and relational location of features in accordance with DLMS specifications. Processing includes digital registration, image correction, image enhancement,

image classification, mensuration and transformation functions. The input imagery is LANDSAT MSS digital data; the output is DLMS digital data for landscape features. Trial production of several one-degree cells was accomplished in 1981; however, the process of merging DIMIAS-produced landscape data with manually compiled cultural feature data for a given production area was found to be inefficient.

Tests were recently completed investigating low resolution, DLMS-type data compiled exclusively from LANDSAT materials using DIMIAS image processing techniques. This data would be used for high altitude aircrew training in areas of low cultural densities and where photogrammetrically derived DLMS data has not been produced.

The potential applications of LANDSAT 4 to DLMS, other auto-carto methods, and charting programs are being investigated using simulated LANDSAT 4 digital data and image processing approaches on DIMIAS.

The DMA also is charged with the responsibility of providing safe and adequate nautical chart coverage for all areas of the world outside the U.S. territorial waters. New vessels possessing greater speeds and deeper drafts demand more accurate and timely

charts to support an increasing traffic volume in unsurveyed or poorly surveyed areas. Hydrographic survey data used to produce the DMA charts are collected by specially equipped survey vessels of the U.S. Naval Oceanographic Office (NAVOCEANO). At the present collection rates, survey ships will require hundreds of years to collect the needed data to produce current and accurate charts. In addition to the high cost of hydrographic surveying, the time from data collection to portrayal on a published, updated nautical chart is extensive. Electro-optical sensors such as the LANDSAT's multispectral scanner (MSS) can be used to augment the slow and expensive process of collecting hydrographic information, as well as for an analysis tool used in the chart compilation process, resulting in a nautical chart that is more responsive to the needs of the maritime community (see Figure 10).

The thematic mapper (TM) in LANDSAT 4 should be significantly more useful for hydrographic applications. The spectral range and wave-length of the TM bands, which are better suited for shallow water feature detection than MSS, combined with the improved spatial resolution of Landsat 4 offer great promise to the DMA charting program.

The application of remote sensors, such as LANDSAT, airborne active/passive scanners and Synthetic Aperture Radar (SAR), to

digital data collection represents a new and promising generation of technology that can and must be exploited to improve digital data production.

FIGURE 9. DIMIAS Workstation for LANDSAT Exploitation

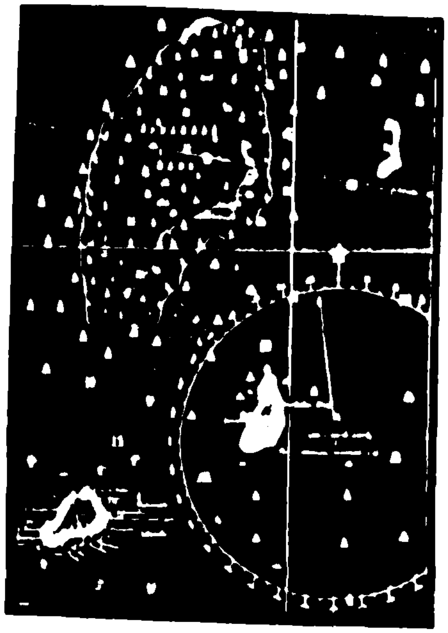

FIGURE 10. Hydrographic Chart Superimposed on LANDSAT Image Showing Uncharted Underwater Shoal (upper right) and Erroneous Underwater Shoal Boundary (upper left)

Additional in-house techniques development and procurement efforts have been pursued as near-term enhancements of present production procedures. These include feature analysis data table (FADT) entry and verification, absolute positioning, manuscript digitizing

equipment, and feature measuring techniques. Three hardware/software systems have been considered to automate the FADT generation which comprises about 15 percent of the total feature analysis effort. They are the OpScan 17 optical character reader, Interactive Feature Analysis Support System (IFASS), and voice entry technology. Under present procedures, absolute positioning of extracted features is accomplished through the use of orthophoto bases. Development of the Continental Control Network and the procurement of an Off-Line Ortho-Photo System has expanded our ability to obtain control information throughout the DLMS program area in graphic or numerical form. Another significant new system is the Automated Graphic Digitizing System (AGDS). AGDS is programmed to support digitization in feature analysis production and in automated cartography. The three independent AGDS scanning, vectorization and editing subsystems provide a significant increase in digitizing capability.

Further extensions of the transition to state-of-the-art methods for DFAD production will be realized with the implementation of the Computer-Assisted Photo Interpretation (CAPI) System. The delivery of the first prototypes began in 1983. This distributed processing system is an analytical stereo-photogrammetric, feature

extraction digital-compilation system. It consists of stand-alone image analysis and compilation stations supported by central processing facilities to perform required pre-processing and post-processing tasks. The basic function of CAPI is to extract all DFAD such as landscape, drainage, and cultural features analytically from stereo imagery of all types.

The CAPI work station under microprocessor control will provide the image analyst the interactive capability to establish, view, and interpret an analytically maintained stereo-model. The stereo viewing system design is based on cross-polarized screen presentation viewed with polarized glasses. The CAPI is designed to allow the analyst to measure required ground dimensions/areas, interactively enter and validate feature description data, digitally compile features in the stereo model, generate a digital feature file, and view the compiled results on a graphics display. CAPI central processor(s) will support the work stations by performing pre-processing for absolute stereo-model orientation and post-processing to transform the work station digitized feature coordinates into geographics. The central processor will manage (store/retrieve) compiled stereo-model data, merge the compiled models to form a digital data set, and generate plots of the digital data.

Implementation of this system will potentially replace manuscript compilation as well as off-line descriptor data processing. DFAD information will, at this point, be collected in a manner comparable with rigorous DTED production using the concept of analytical systems for film-based imagery.

The Clustered Carto Processing System (CPS) was installed in early 1983. The CPS (Figure 11) is designed to provide a set of interrelated automatic and interactive functions to accept digital data from AGDS, CAPI, DIMIAS, and IFASS and perform various transformations on the data. These transformations include geometric and geodetic transformations: merging and panelling operations; editing, correcting validation, and output formatting. CPS represents the state-of-the-art in large volume digital cartographic data production systems. Hardware designs are based on two 32-bit super minicomputers for processing and one super mini serving as an edit subsystem. Communication lines allow data transfer and system backup. Shared and local disk data storage pools total 2,304 megabytes.

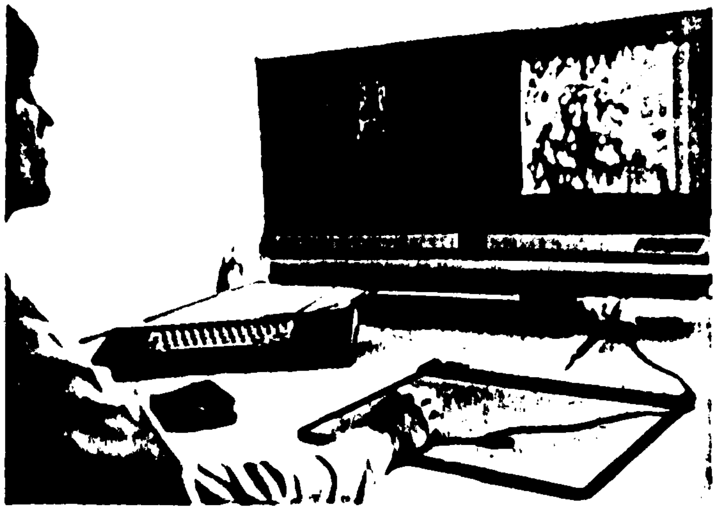

FIGURE 11. Clustered Carto Processing System Workstation

DIGITAL DATA ANALYSIS

The digital data produced by the Defense Mapping Agency supports a wide variety of products, including input to electro-optical sensor simulators, guidance systems, and automated cartographic systems. The accuracy and quality of the data must be precisely known to assure reliability of its use in critical systems. In order to facilitate the analysis of these data bases, various types of sophisticated display systems have been developed. Initial techniques were incorporated into production quality control units called Image Manipulation Stations. The IMS (Fig. 12 and [illegible] will be eventually integrated into the Digital Data Base Analysis System, a system being developed to manage the DMA digital cartographic data bases.

of prototype data bases for use in advanced training simulators, as well as to ensure the quality of, and coherence between the various digital data bases prior to new data insertion into the master cartographic data base files (see cover figures).

The Sensor Image Simulator performs five major functions:

1. Digital Data Base File Input and Output.
2. Off-Line to On-Line Data Base Transformation.
3. Sensor Simulation.
4. Interactive Data Base Editing.
5. Software Development and Maintenance.

The SIS brings together, in a self-contained integrated hardware/ software facility, a significant capability to evaluate the digital data bases. All operations are conducted under interactive control. Both the software structure and operations sequence reflect a top-down implementation philosophy wherein principal control functions are resident at the top of the hierarchy and functions concerned with processing individual data elements are at the lowest. The system is implemented in such a fashion that future changes in processing can be accomplished at the highest level of system software support.

In order to perform interactive analysis of the digital files, digital terrain elevation data may be used to generate color coded contour plots and line profile displays. An alternative is to color code the matrix terrain data directly. While analysis of these matrix image displays is superior to trying to perform analysis by visual inspection of the data in printed numerical matrix format, they only provide for a low spatial resolution analysis capability. Shaded relief display with variable illumination adds additional information for analysis of all types of matrix data, and is particularly meaningful for cartographic data because of the relationship to the physical world. Higher spatial resolution analysis of the shaded relief display may be gained by applying photogrammetric models to generate pseudo-stereo-pairs of images in which spike points are apparent under stereoscopic analysis. These techniques, used singly or in combination, allow for data base analysis far superior to techniques of a decade ago, but they are not enough.

In order to perform high resolution anomaly analysis of data bases for the purpose of either quality control or information gathering, advanced techniques are required. These techniques include convolution filtering, specialized color representation, digital fourier analysis, and computer generated sensor simulation (see Figures 13, 14).

Convolution filters have been used very effectively to enhance matrix data to show processing anomalies as well as where data has been merged from different production equipment, different stereo models, different production methods, variable requirement specifications, and even from different analysts. These types of filters are used extensively by the image processing community to detect edge differences, and then to reapply the differences to sharpen the original image. They also have been shown to be a powerful tool for the analysis of cartographic data bases.

For the purpose of determining compatability between data types, such as between digital terrain and culture data, simple color coding and overlay in Red-Green-Blue (RGB) space may not be sufficient. A more powerful technique employs coding each data type along an Intensity-Hue-Saturation (IHS) axis and then converting from the IHS space to RGB space prior to display. Since the visual perception process can distinguish variation between IHS, the data types can be overlayed without a merging of colors, and therefore, without an information loss. Various cultural thematic displays may be overlayed on variably illuminated terrain displays.

The DMA is beginning to explore the potential of using digital fourier analysis for anomaly detection and subsequent filtering

of the terrain data. The capability of digital generation and interactive display of two-dimensional fourier transformations of the terrain data in conventional frequency vs azimuth as well as profile displays are shown in Figures 15 and 16. A variety of digital pass and rejection filters such as shown in Figure 17 have been applied to these transforms for anomaly removal.

Finally, and probably unique to cartographic data bases, is the technique of computer generating landform scenes as seen by various visual and electro-optical sensors (Fig. 5, 6). This allows for a final quality control analysis of information content, and also has been very valuable in the definition of data base requirement specification.

The impact of this interactive system development to data base display and analysis has been enormous. Not only has there been a greatly increased capability for the degree and sophistication of quality control, but there is an associated cost savings in both the quality control review process, and in the resultant expense of using cartographic data bases containing anomalies.

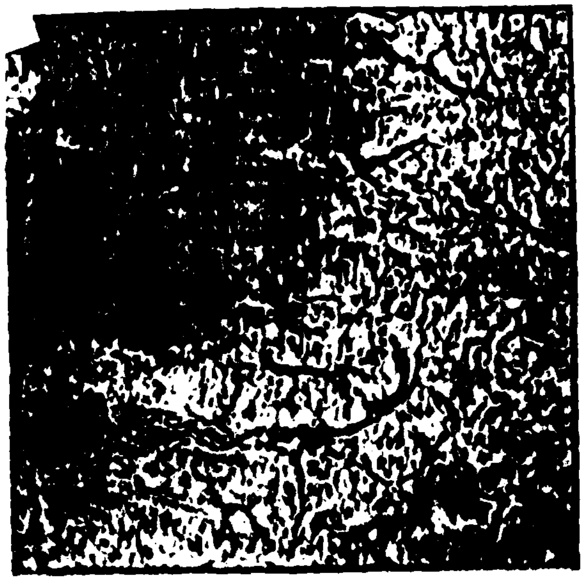

FIGURE 13. Digital Terrain Elevation Data Gradient Magnitude Display

FIGURE 14. Digital Terrain Elevation Data 5x5 Edge Filter Showing Inserted Data Patch Anomaly

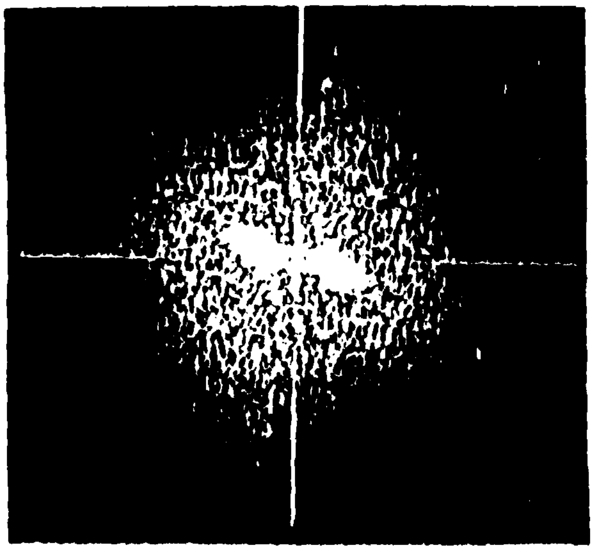

FIGURE 15. Digital Terrain Elevation Data Fourier Transform Display

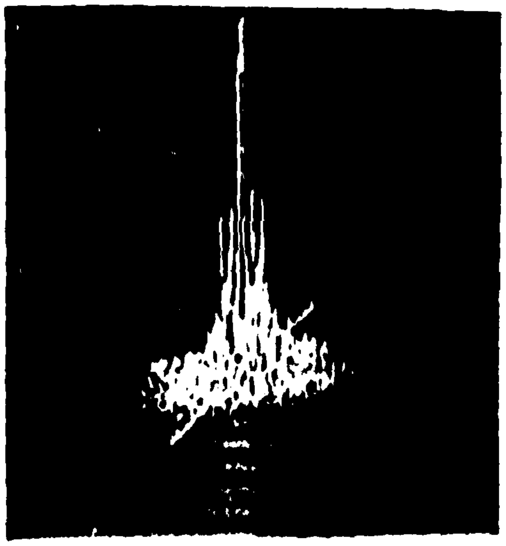

FIGURE 16. Digital Terrain Elevation Data Fourier Transform Profile Display

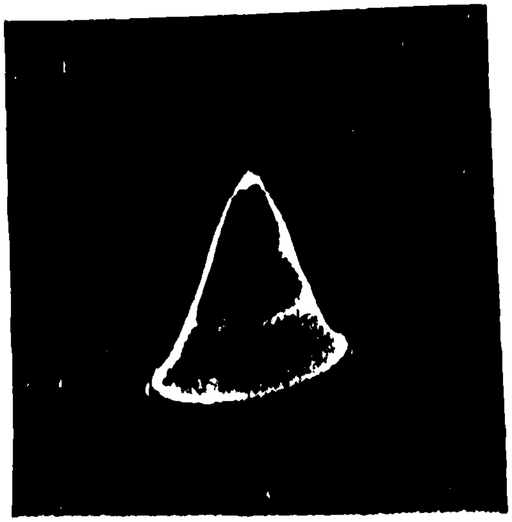

FIGURE 17. Digital Exponential Pass/ Rejection Filter

PROJECTED EVOLUTION OF DATA BASE PRODUCTION

The labor intensiveness of the present digital data base production process and the worldwide extent of DLMS requirements has led DMA to explore automation as a means of decreasing production costs. This is being accomplished within the technical base existing at DMA and via research and development programs through academic, industrial, and governmental institutions. Initial goals to increase production of current DLMS Level I and II data are being addressed by the implementation of specialized automated processing systems and computer assisted photo-interpretation stations. In

order to establish the capability to produce anticipated data types and resolutions required by 1985-1990, the DMA is expanding its Artificial Intelligence and Image Understanding Programs for the technology base required to support the development of interactive, digital data production systems.

Studies were completed by DMA in the field of digital image processing, which focus on investigations of the applicability and feasibility of all digital production systems. Additional Pilot Digital Operations (PDO) studies are the Interactive Feature Extraction Study and Applied Pattern Recognition Testing. These studies were carried out on a digital image processing test facility called the Remote Work Processing Facility (RWPF). The RWPF is equipped with image manipulation and graphic processing algorithms (including some pattern recognition schemes and machine intelligent control structures) as interactive operations to aid in detection/identification, classification, delineation, and digital recording of features. Experiments will be conduced on the RWPF to aid in the definitions, specifications, and configurations of future digital production equipment.

To support both image analysis and digital data production systems, DMA has developed a general purpose digital image processing

software package to accomplish image restoration, enhancement, noise removal, and geometrical warping. Spatial convolution filters, pixel histogram manipulations, transform coding and filtering and compression techniques are included. Consider the following example using a LANDSAT image containing transmission noise (see Figures 18 and 19). A 1 x 3 pixel medial filter was applied to remove the noise. This was followed by a histogram equalization procedure to enhance the contrast, and then image warping was applied to rectify the image to the proper geometry.

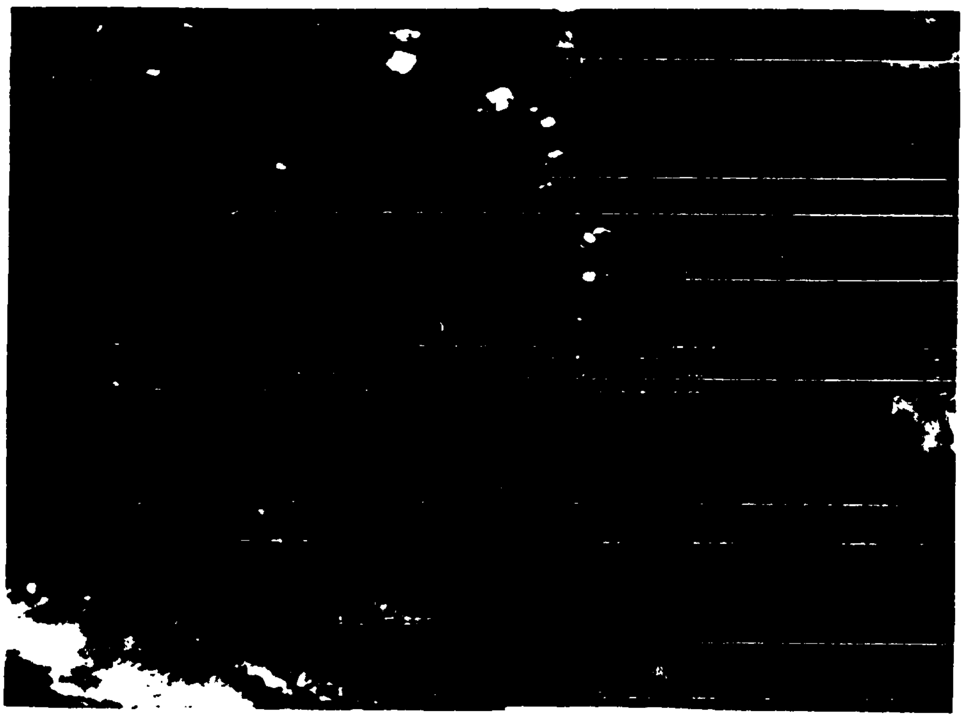

FIGURE 18. Original LANDSAT Image With Noise

FIGURE 19. Enhanced and Rectified LANDSAT Image

A more powerful technique for enhancement is shown in Figures 20a and 20b. Here a 5 x 5 convolution matrix was developed to model a second order Laplacian enhancement with variable weighting factors. The original image is of the Martian surface taken from the Viking orbiter spacecraft. The enhanced image display optimizes

both gray level improvement and edge sharpening. A variation of this technique can be used for edge only displays, as shown in Figures 21a and 21b.

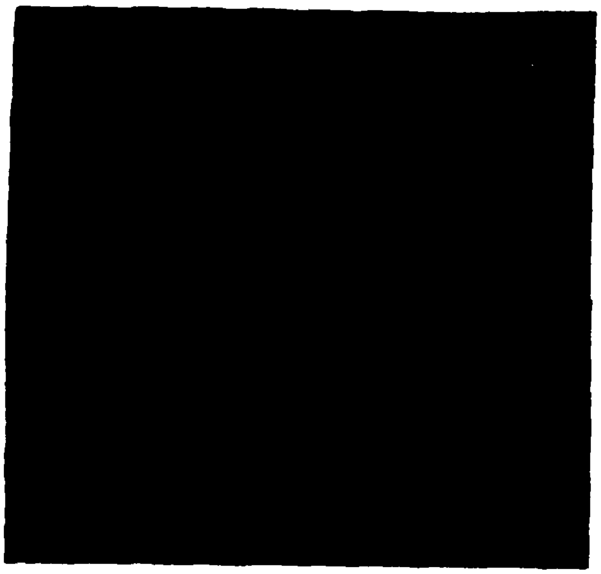

FIGURE 20a. Original Viking Mars Image

FIGURE 20b. Second Order Laplacian Enhanced Viking Image

FIGURE 21a. Original Image

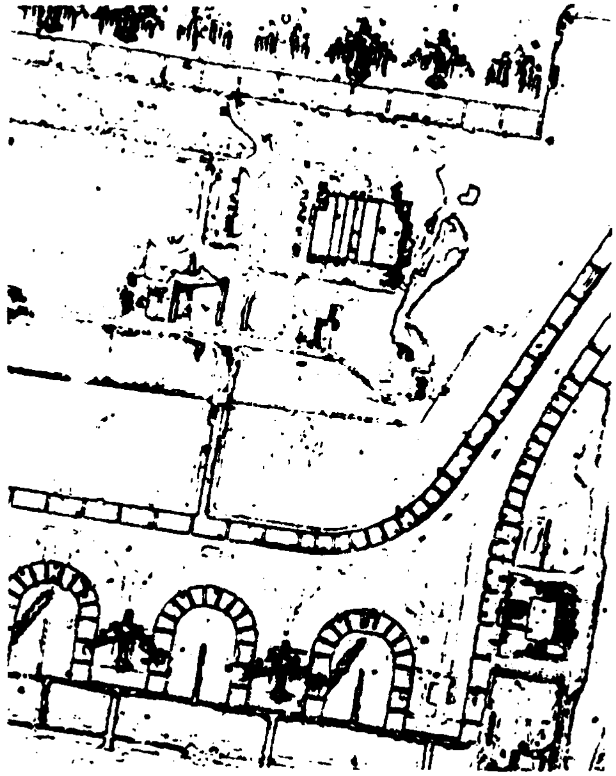

FIGURE 21b. Edge Display

THE CHALLANGE

The DMA is faced with the tremendous problem of automating the digital data and chart production processes. Some limited successes have resulted from the DMA R&D program. DMA, however, is a long way from solving the total digital production problem. To this end, Technical Base Capability Objectives have been established for Automated Feature Analysis and Mass Data Base Management. The Automated Feature Analysis objective contains four broad tasks:

1. Automated Universal Stereo Reconstruction.

2. Relational Data Base Structures.

3. Automated Feature Extraction.

4. Multi-Spectral Source Exploitation.

The Mass Data Base Management objective is described by:

1. Storage media and architectures.

2. Data base structures for images and products.

3. Image compression and alternative product data base structures.

4. Interactive data base storage access, and management with a variety of user interfaces.

The success of the DMA development of these capabilities is crucial to the support of the future requirements for digital data production. In addition, the DMA is developing a wide variety of digital softcopy production systems to integrate these software concepts with the vast amount of source input in order to approach the goal of automated digital cartographic production. Numerous technical problems must be solved in the areas of artificial intelligence, image understanding, telecommunications, large digital image and product data base operations, digital data structures, and digital production techniques. The Defense Mapping Agency has accepted the challenge of solving these problems, and is actively pursuing university, government, laboratory, and commercial contractor support.

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